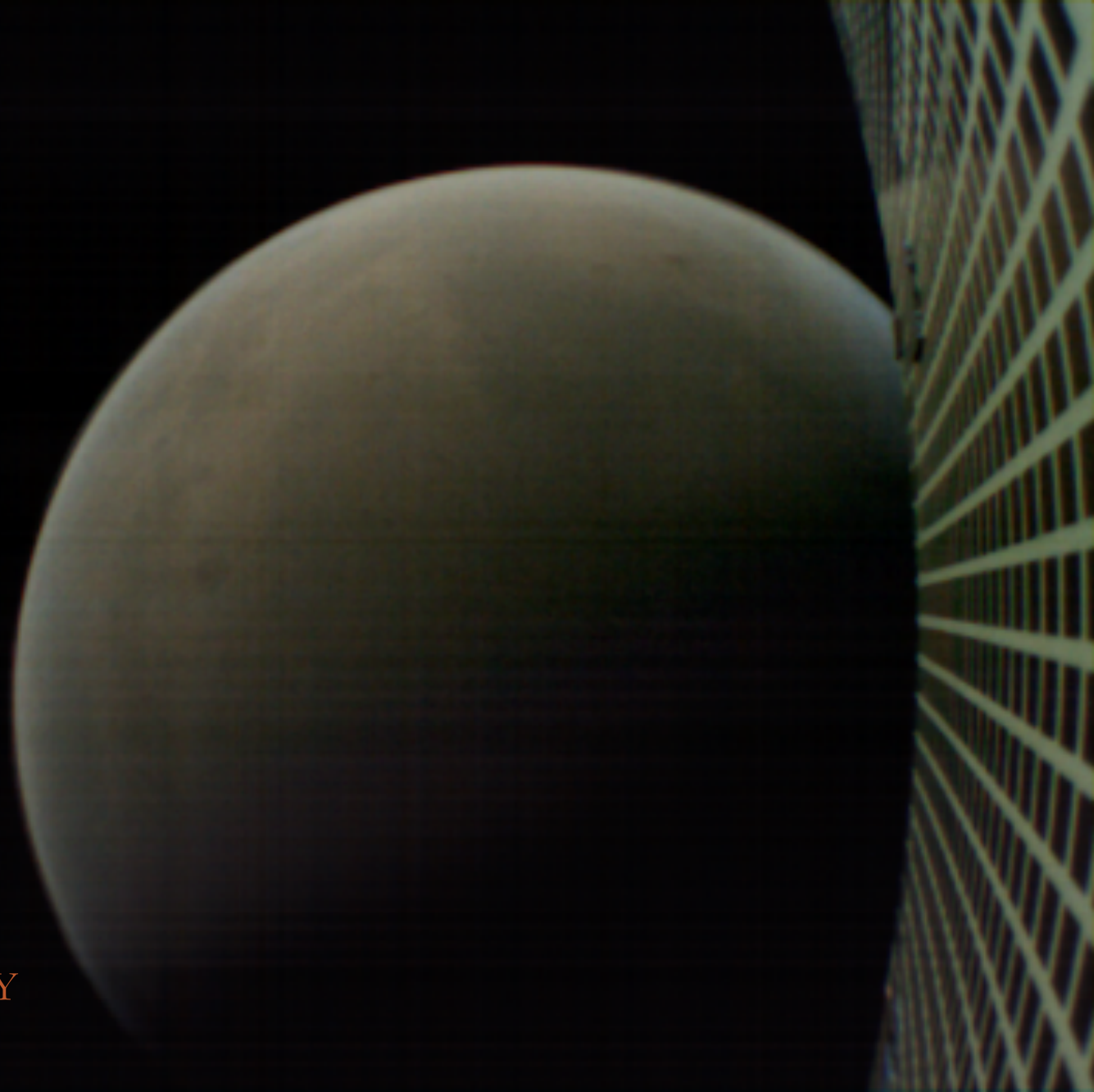


*2019 Low-Cost Planetary Missions Conf.
Toulouse, France, 3-5 June 2019*

Iris Deep Space Transponder: MarCO's Telecom System

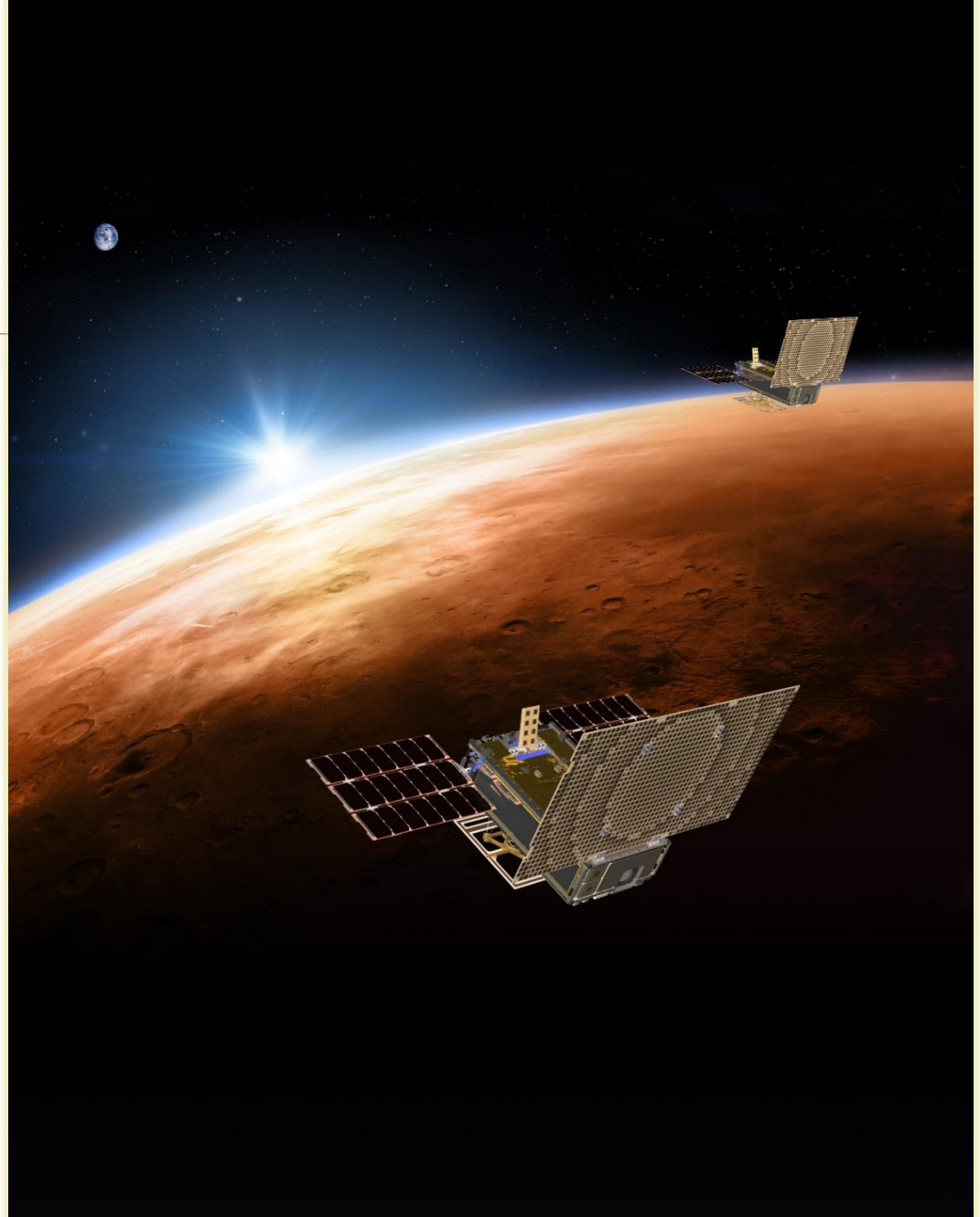
SARAH HOLMES

JET PROPULSION LABORATORY AT THE
CALIFORNIA INSTITUTE OF TECHNOLOGY



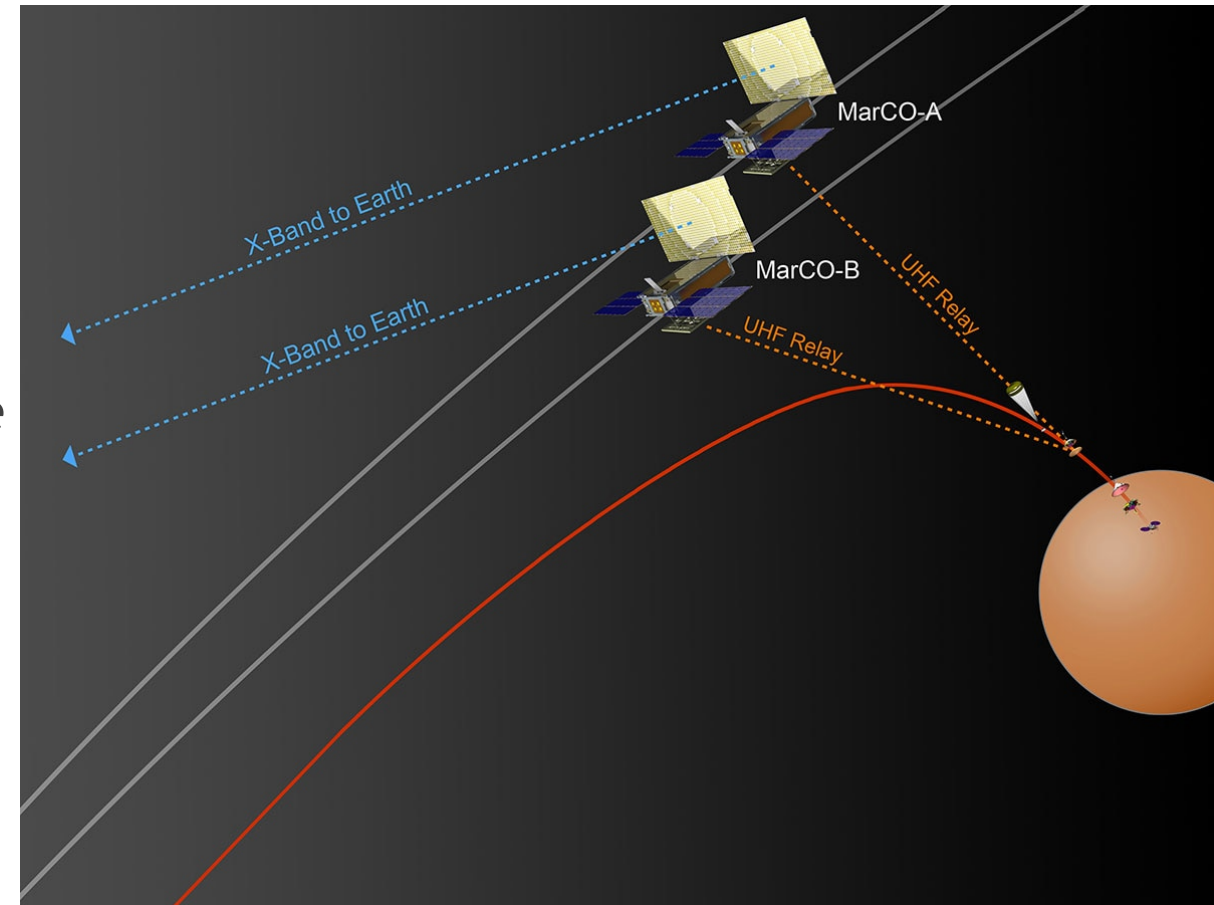
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- Hardware Specifications
- Firmware/Software Architecture
- Testing Pre-Launch
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- Iris at Mars
- Current State of MarCO and Iris



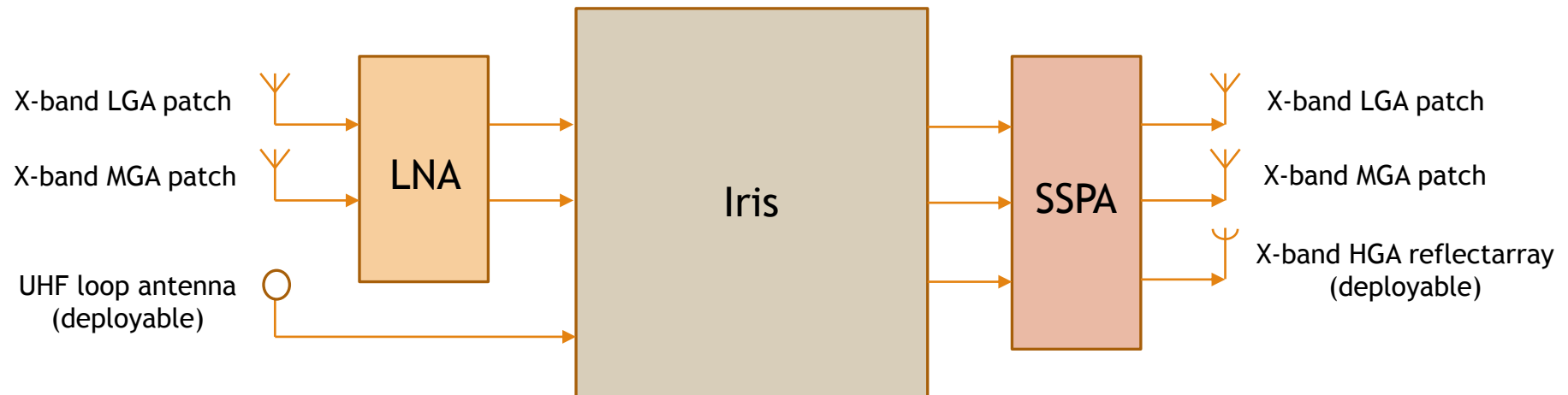
MarCO Mission Overview

- Real-time data relay of InSight's entry, descent, and landing (EDL) to the surface of Mars
- Bent-pipe relay:
 - UHF receive from InSight to MarCO's Iris,
 - X-band transmit from MarCO's Iris to DSN
- Technology demonstration: test and validate several subsystems, including Iris
 - InSight's success is independent of MarCO's success (MRO performs EDL recording as well)
- Additional facts:
 - Two MarCO spacecraft, for redundancy
 - First deep space cubesats
 - MarCOs launch with InSight, but separate and fly independently to Mars



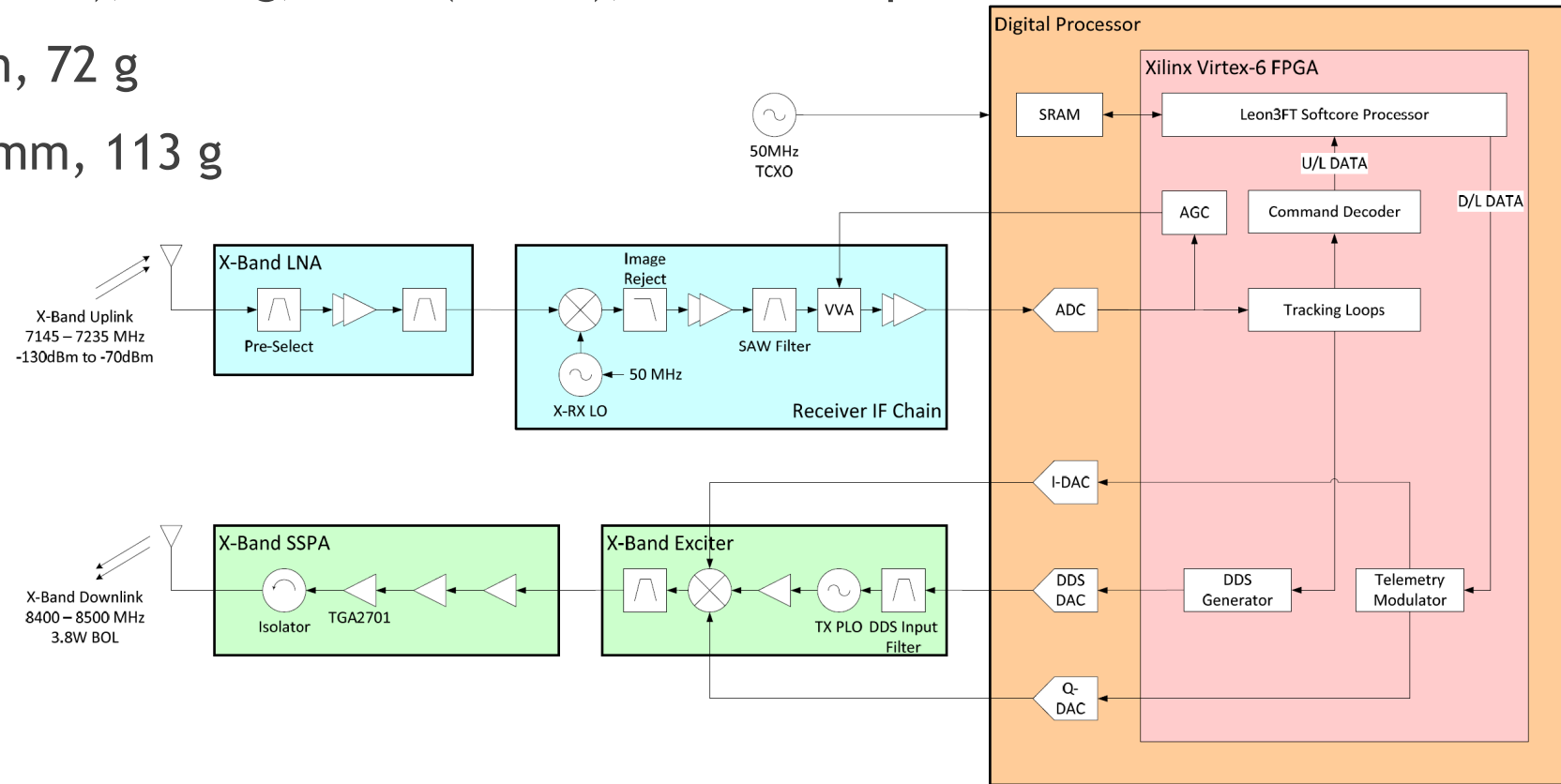
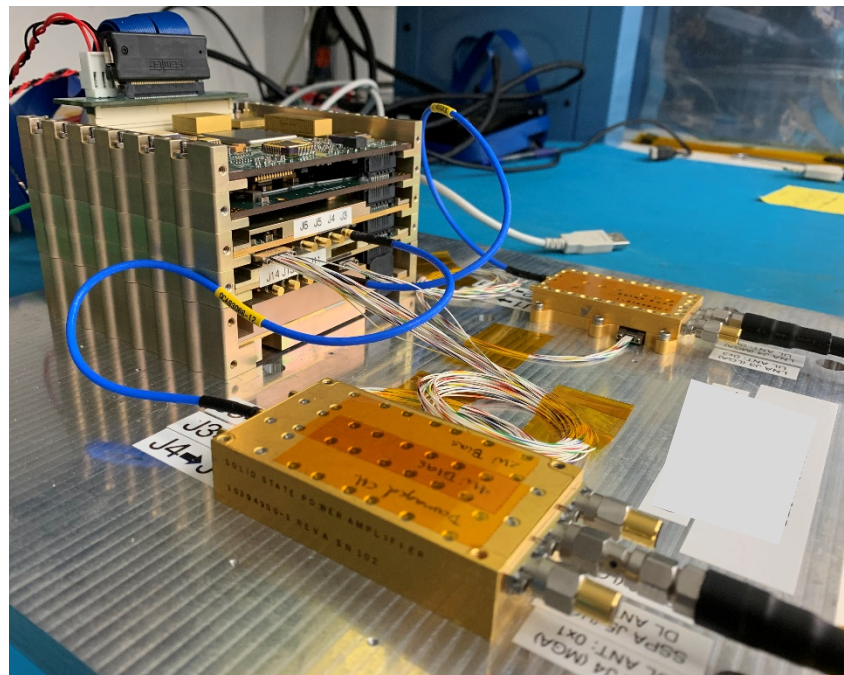
Iris V2.0 Overview

- Five boards: digital, power, X-band exciter, X-band receiver, UHF receiver
- Communicates with ground at X-band
 - CCSDS: AOS (downlink), TC (uplink)
- Leveraged Iris V1.0 design, but updated hardware and added processor/software



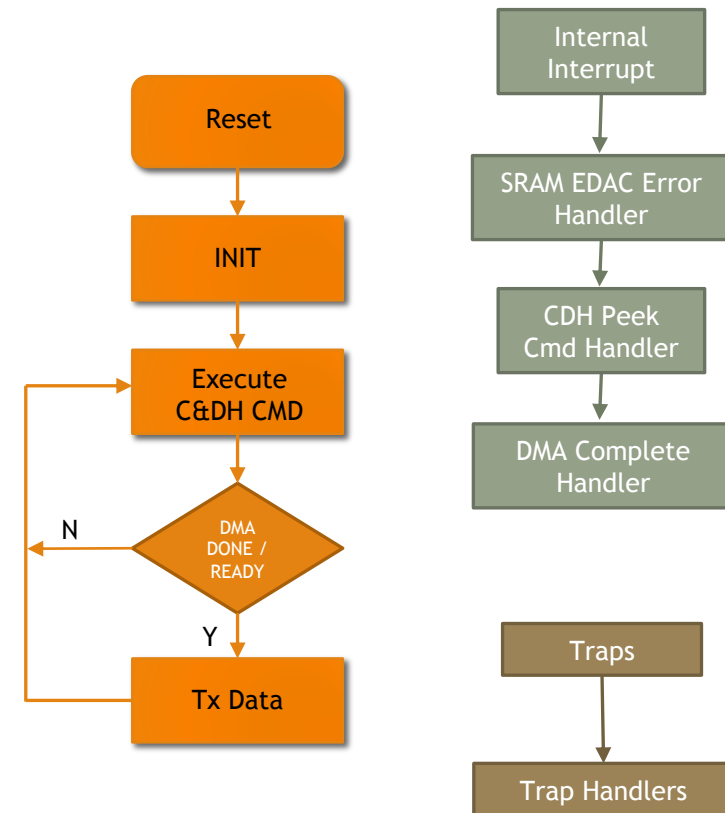
Hardware Specifications

- Iris: 115 x 100 x 85 mm (~1 U), 1.2 kg, 35 W (Tx/Rx), 4 W RF output
- LNA: 69.4 x 47.5 x 13 mm, 72 g
- SSPA: 86.6 x 42.7 x 17.8 mm, 113 g

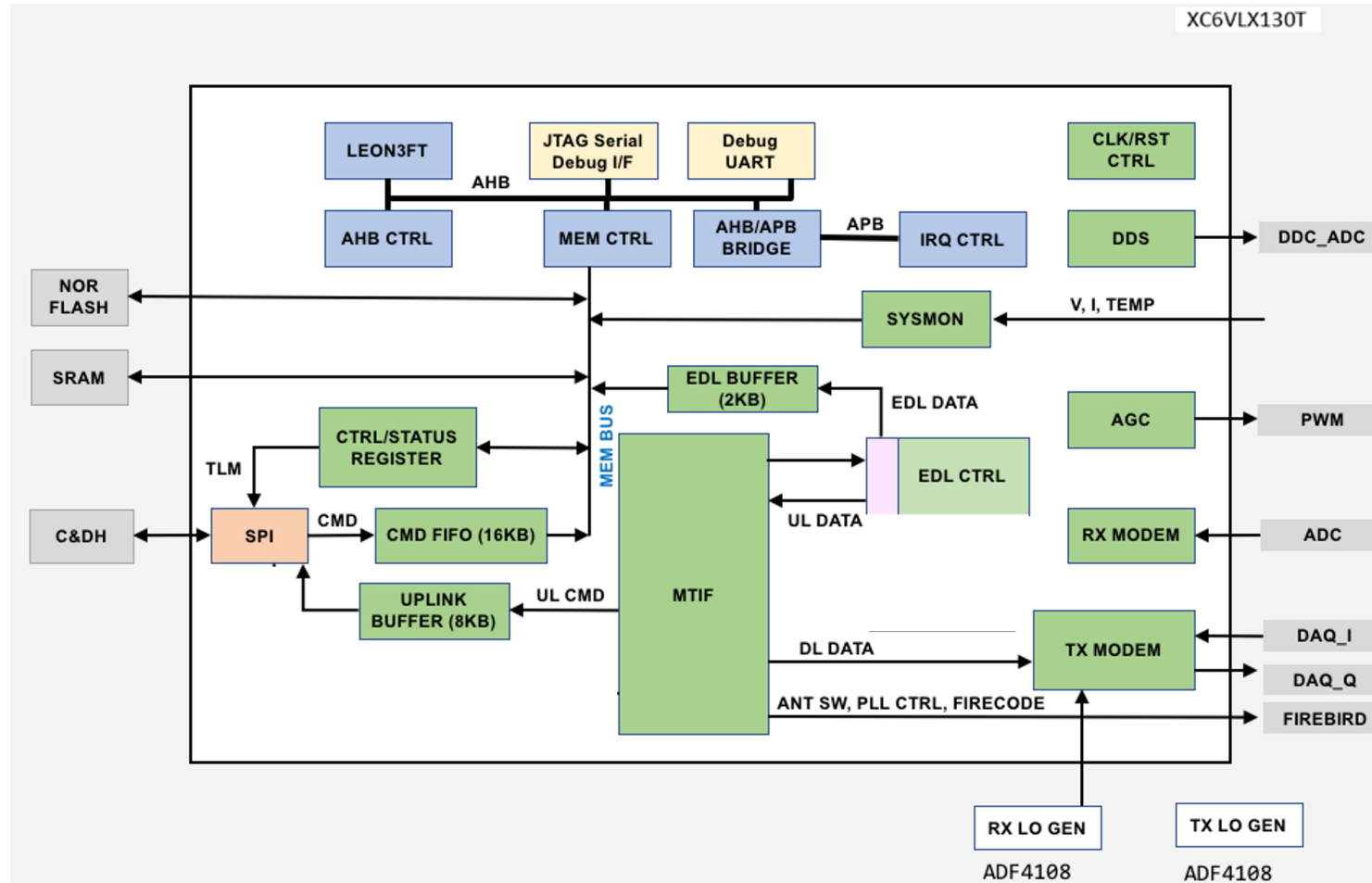


Firmware/Software Architecture

- Firmware utilizes Virtex-6 FPGA
- MTIF and modem processor are MSL heritage
- LEON3-FT softcore processor instantiated in firmware
- Single-threaded software running at 50 MHz
- Memory:
 - NOR flash (32 MB): firmware/software image storage
 - SRAM (2 MB): software execution and data storage



Firmware Block Diagram



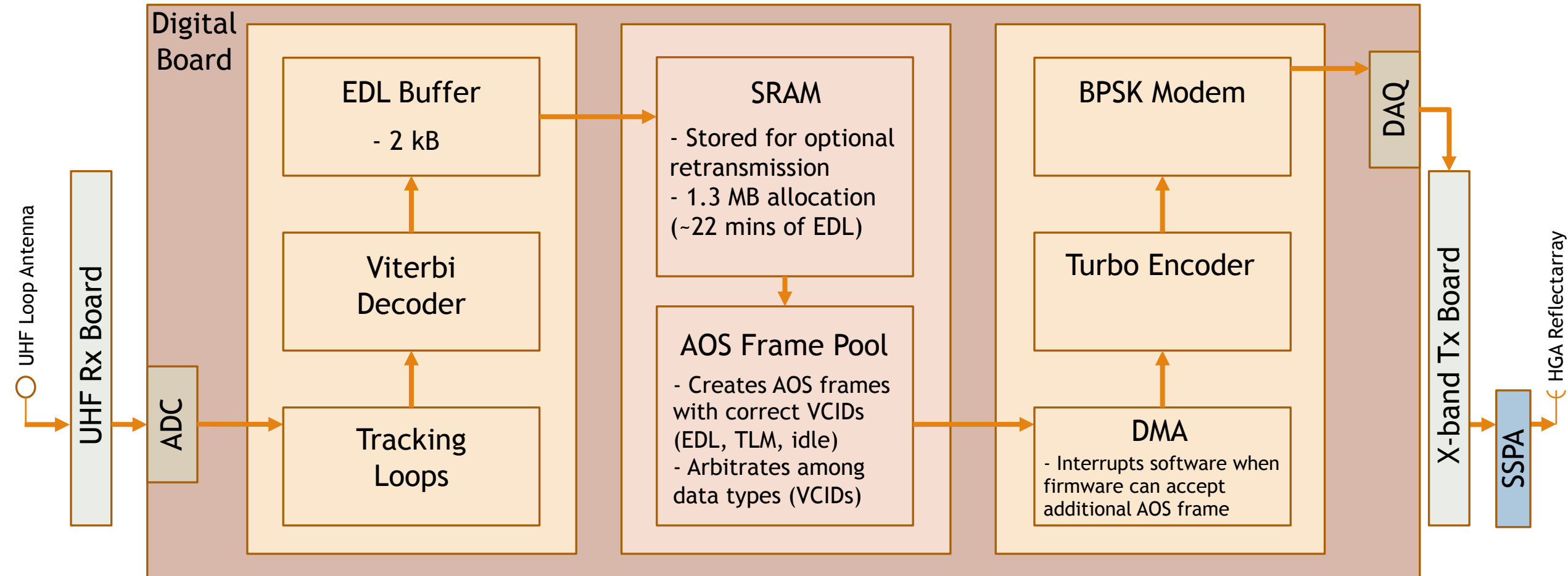
Modes and Configuration Options

Mode	Receiver	Transmitter	Ranging	DDOR	Coherency	Configuration Parameter	Available Settings
X-Band Receive-Only	LNA, 62.5 bps, PCM/PSK/PM 16 kHz sine	--	--	--	--	Uplink Data Rate	62.5, 1000 bps
X-Band Transmit-Only	--	SSPA, 62.5 bps, PCM/BPSK/PM 25 kHz square	Off	Off	Off	Downlink Data Rate	62.5, 1000, 8000 bps
X-Band Transmit/Receive	LNA, 62.5 bps, PCM/PSK/PM 16 kHz sine	SSPA, 62.5 bps, PCM/BPSK/PM 25 kHz square	Off	Off	On	Downlink Data Encoding	Turbo 1/6, Manchester on/off, Pseudo-Randomization on/off
Ranging - No Data	LNA, 62.5 bps, PCM/PSK/PM 16 kHz sine	SSPA	On	Off	On	Exciter Mod Index	0 to 138 degrees
DDOR - No Data	--	SSPA	Off	On	Off	Uplink Antenna	X-band MGA, X-band LGA
Bent Pipe	UHF Rx, 8000 bps, Viterbi decoder, direct carrier	SSPA, 8000 bps, BPSK square, direct carrier	Off	Off	Off	Downlink Antenna	X-band HGA Reflectarray, X-band MGA, X-band LGA
Other Modes	Additional commands may be used to configure the Iris into modes not defined above. <i>For example, if Ranging with Data is desired, command Iris to Tx/Rx mode, and then send a command to enable ranging.</i>						Other parameters include subcarrier frequency, coherency, ranging, etc.

Note that the configurations in the modes to the left are the default settings, and can be changed with additional commands.

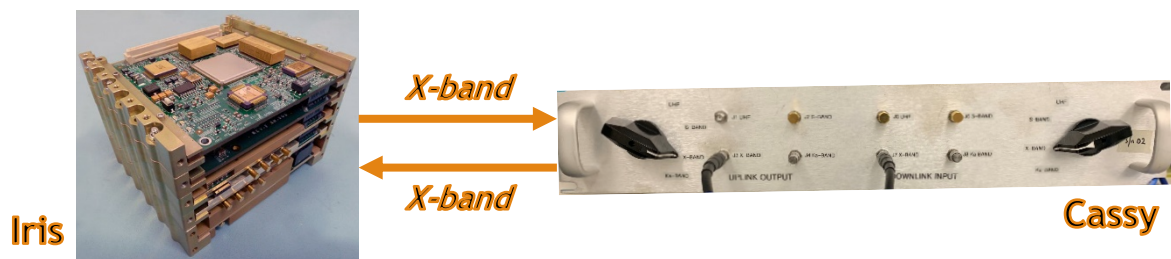
Data Flow During Bent-Pipe

Rx/Tx Boards
HW Components
FW Components
SW Components

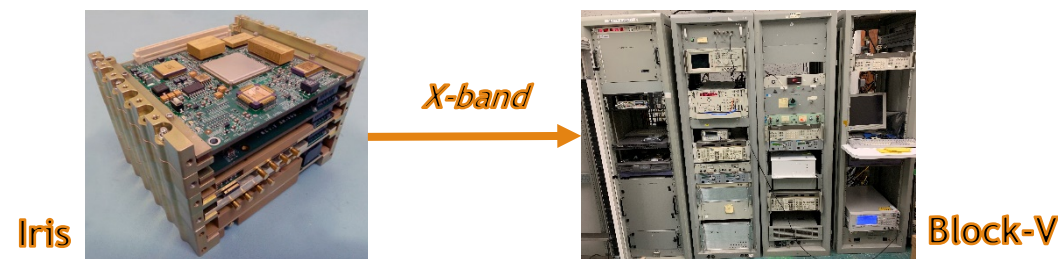


Testing Pre-Launch

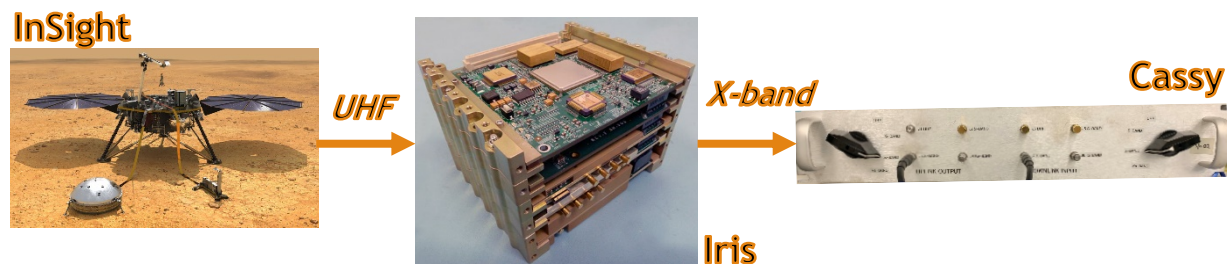
- Ambient testing
 - Location: JPL (California)
 - Utilized Cassy GSE (developed with Iris)



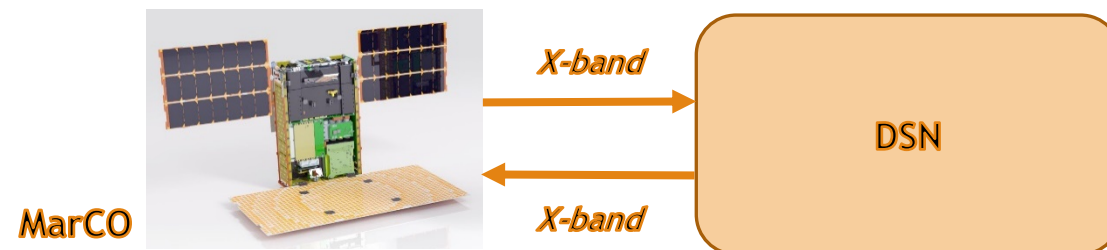
- Block-V Receiver tests
 - Location: JPL (California)
 - 5th generation DSN receiver currently used at all DSN complexes



- InSight compatibility
 - Location: Lockheed Martin (Colorado)
 - Unit-level (pre-integration with MarCO)

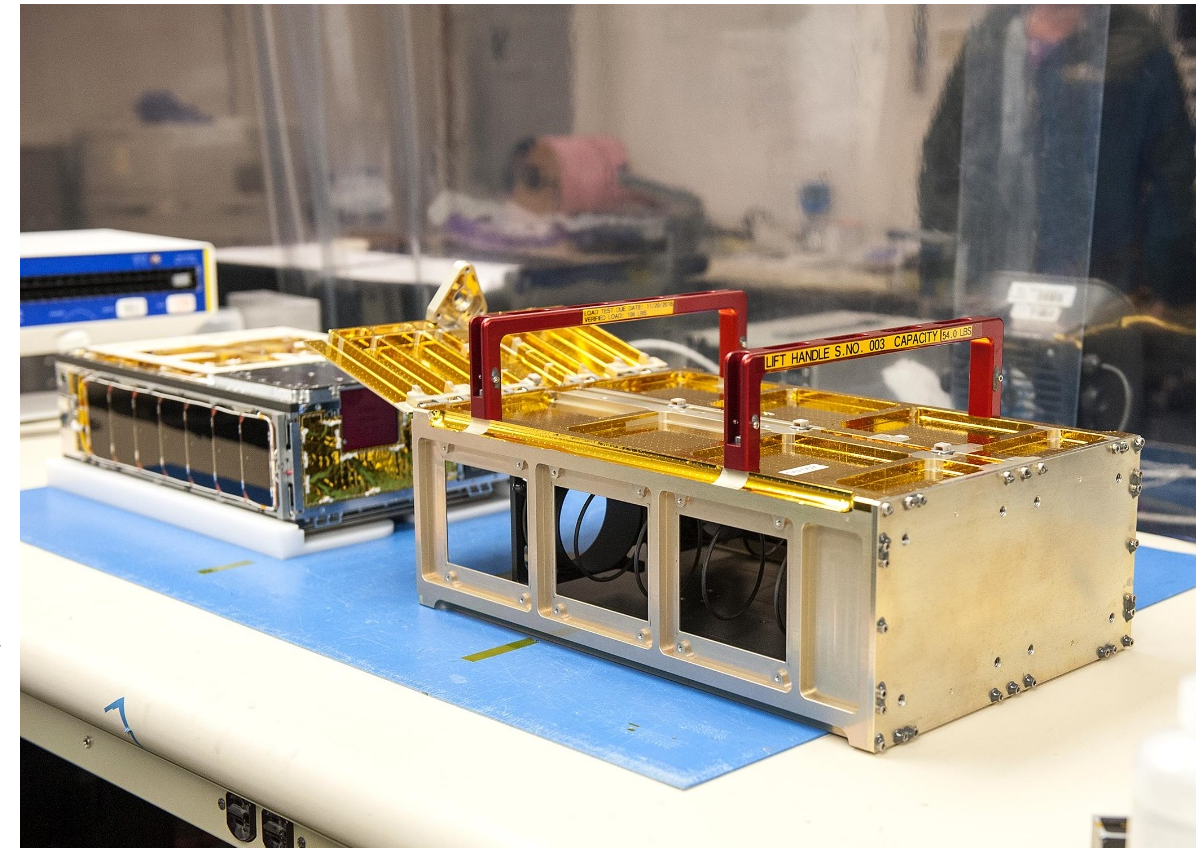
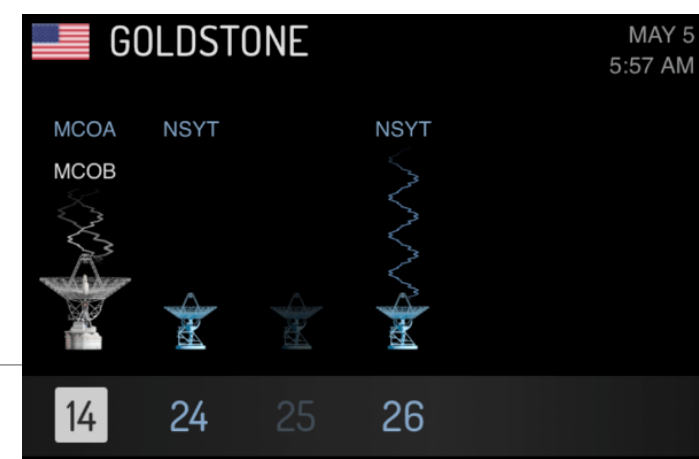


- DSN compatibility
 - Location: DTF-21 (California)
 - Spacecraft-level (post-integration with MarCO)



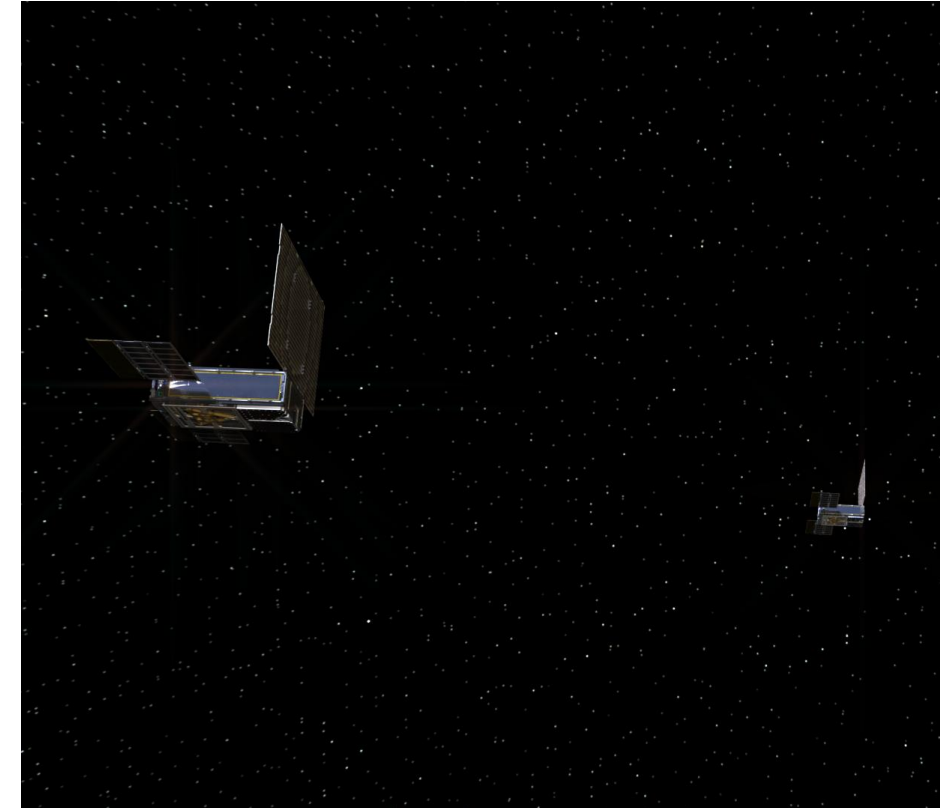
Iris on Launch Day

- Launch: May 5, 2018, Vandenberg Air Force Base
- MarCOs successfully deployed after InSight
- First Contact:
 - Iris beacons to say “I’m alive!”
 - Transmits telemetry data
 - On schedule:
 - MarCO-A: ~5:55am, 5 mins
 - MarCO-B: ~6:05am, 5 mins
 - Nominal telemetry on both SC
- Commanding performed during later pass
- Successful deployment of X-band reflectarray and UHF loop antenna



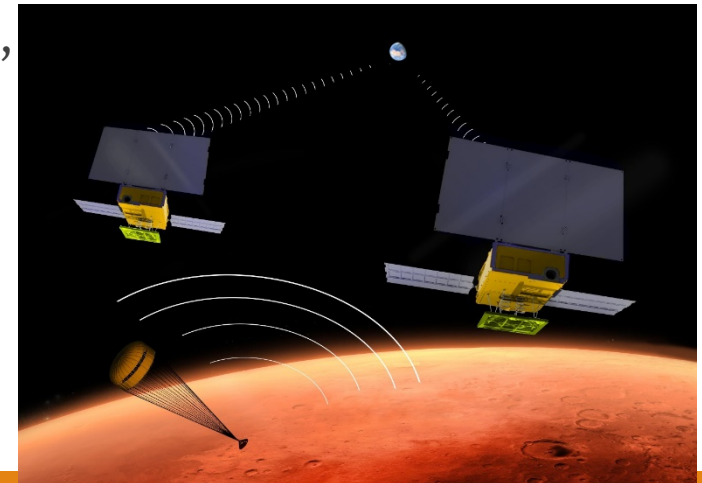
Iris During Cruise: Continuous Operations

- Commanding (uplink data)
 - Pre-loaded command sequences in MarCO flight computer, allowing for some autonomous functionality
 - Uplinked new command sequences from ground as desired
- Telemetry (downlink data)
 - Downlinked telemetry data containing spacecraft and subsystem health and status
 - Also transmitted images as available
- Navigation
 - Ranging Mode receives ranging signal (carrier tone) from ground and retransmits ranging signal back to Earth
 - DDOR Mode (delta differential one-way ranging) generates and transmits DDOR tones, which are received by multiple ground stations



Iris During Cruise: Special Operations

- HGA characterization
 - Verification that HGA in good condition after launch (performed on both SC)
 - Point the antenna to different attitudes and measure how the receive power changes on the ground
 - Nominal boresight, then +/- 2 degrees on different axes
- In-flight test of bent-pipe (EDL) mode
 - Verification that UHF antenna in good condition after launch (performed on both SC)
 - UHF transmit from Stanford ground station (simulating InSight) to Iris, X-band transmit from Iris to DSN
 - Due to relative locations of antennas on MarCO, both MGA and HGA were used during this test
- Receive tests with Morehead State University ground station

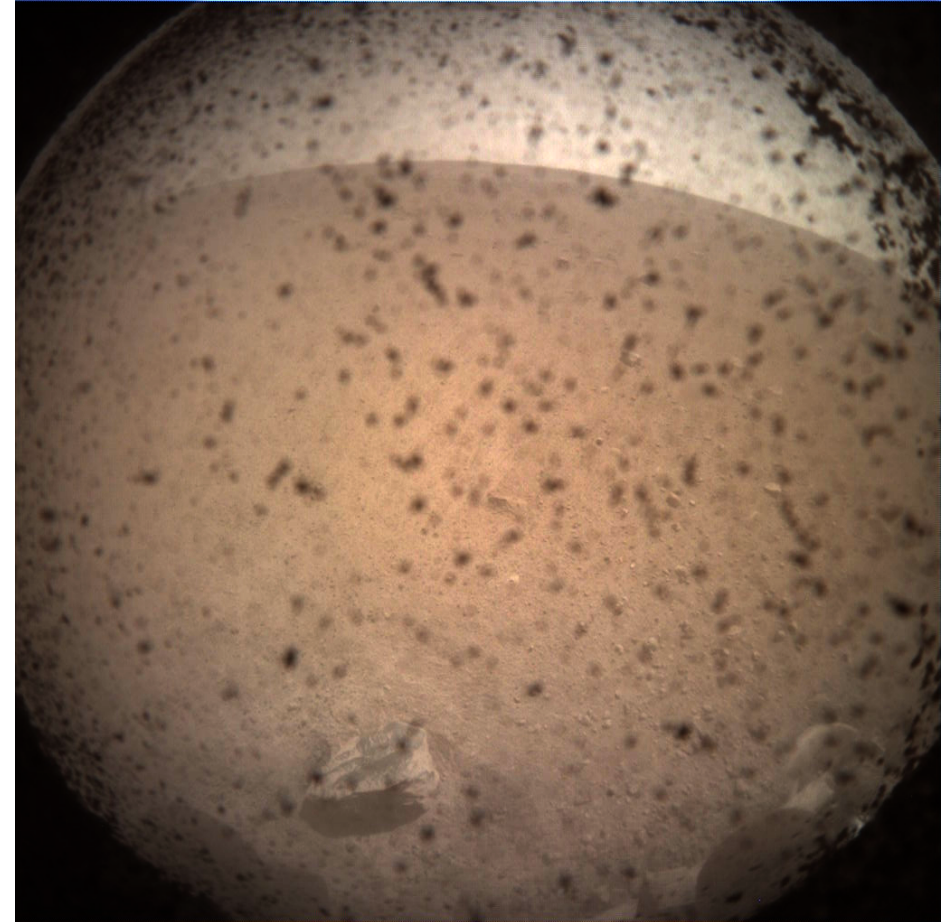


Iris During Cruise: Tech Demo Exercises

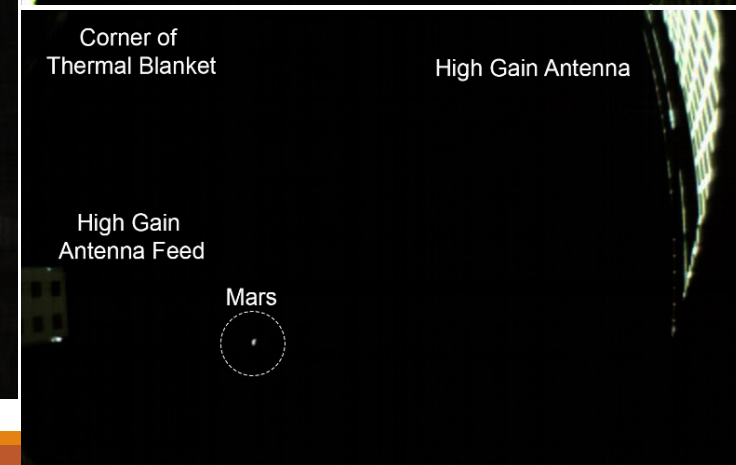
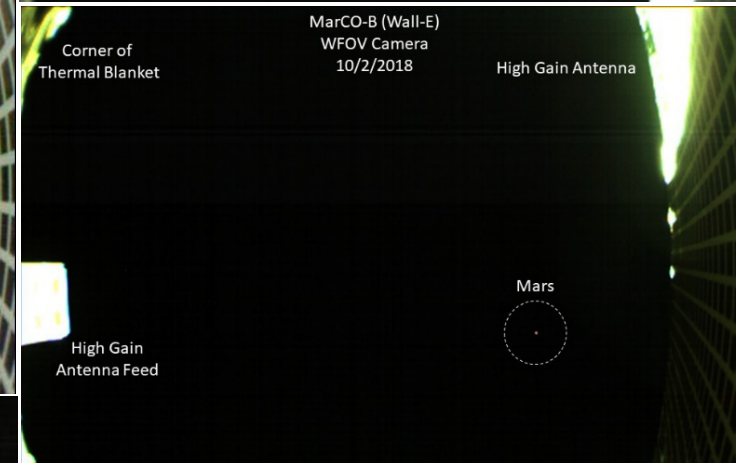
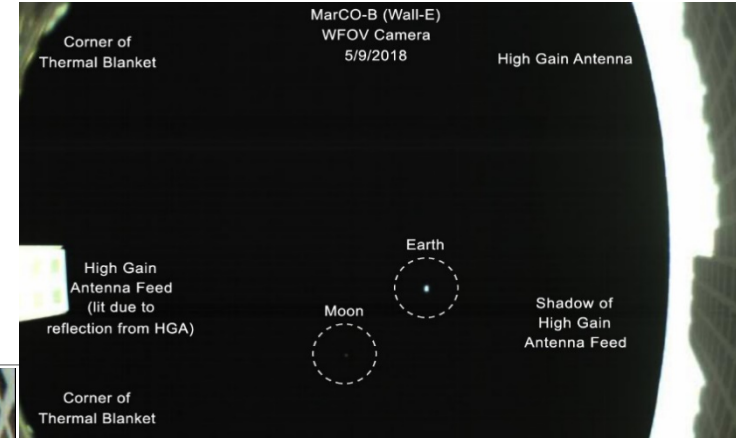
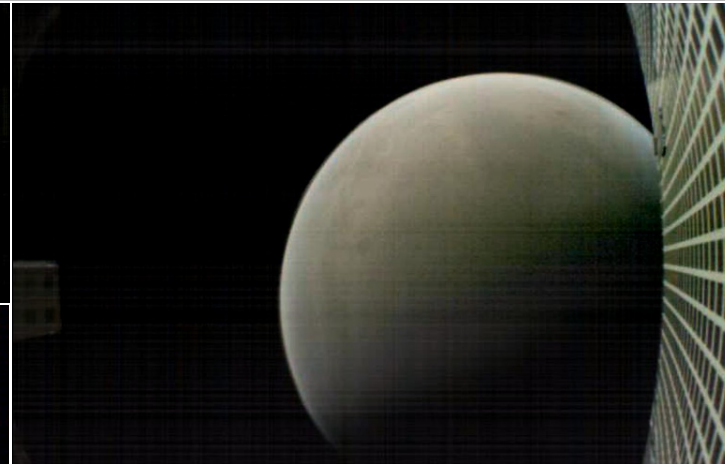
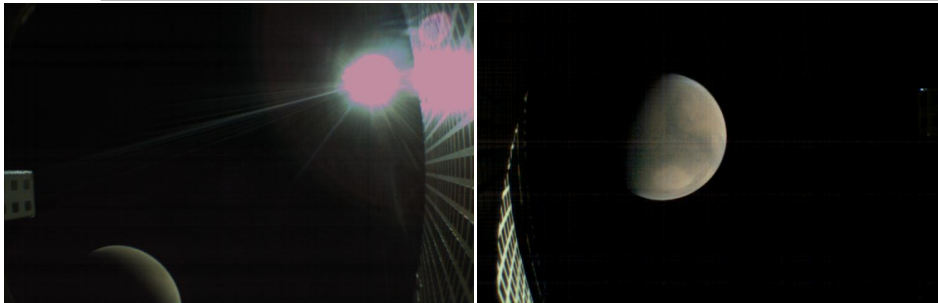
- Attempted many Iris configurations in flight to exercise as much functionality as possible (technology demonstration)
- Identified and uploaded new command sequences (did not reprogram Iris)
- Verified on MarCO Iris spare unit with Cassy GSE, and on MarCO SC testbed
- Examples:
 - Tx/Rx with Ranging
 - Additional Data Rates
 - Downlink rate of 16 kbps required encoding of Turbo 1/3 instead of Turbo 1/6 to comply with NTIA license agreement
 - Turbo 1/6 at 8 kbps = Turbo 1/3 at 16 kbps = 96 kHz
 - Carrier-Only Downlink
 - Adjusting Data Arbitration
 - Single-threaded software is deterministic, so able to disassemble flight image to find memory location for data arbitration variable
 - Poked in flight to allow for alternate prioritization among VCIDs (EDL data vs TLM data)

Iris at Mars: Mission Success!

- Successfully completed EDL with zero data loss
 - Iris transmitted all data that it received
 - Each MarCO collected more data than MRO!
- Performed retransmission post-EDL
- MarCO enabled quick reception of InSight's first image on Mars
 - Utilized tech demo exercises including data arbitration and data rates

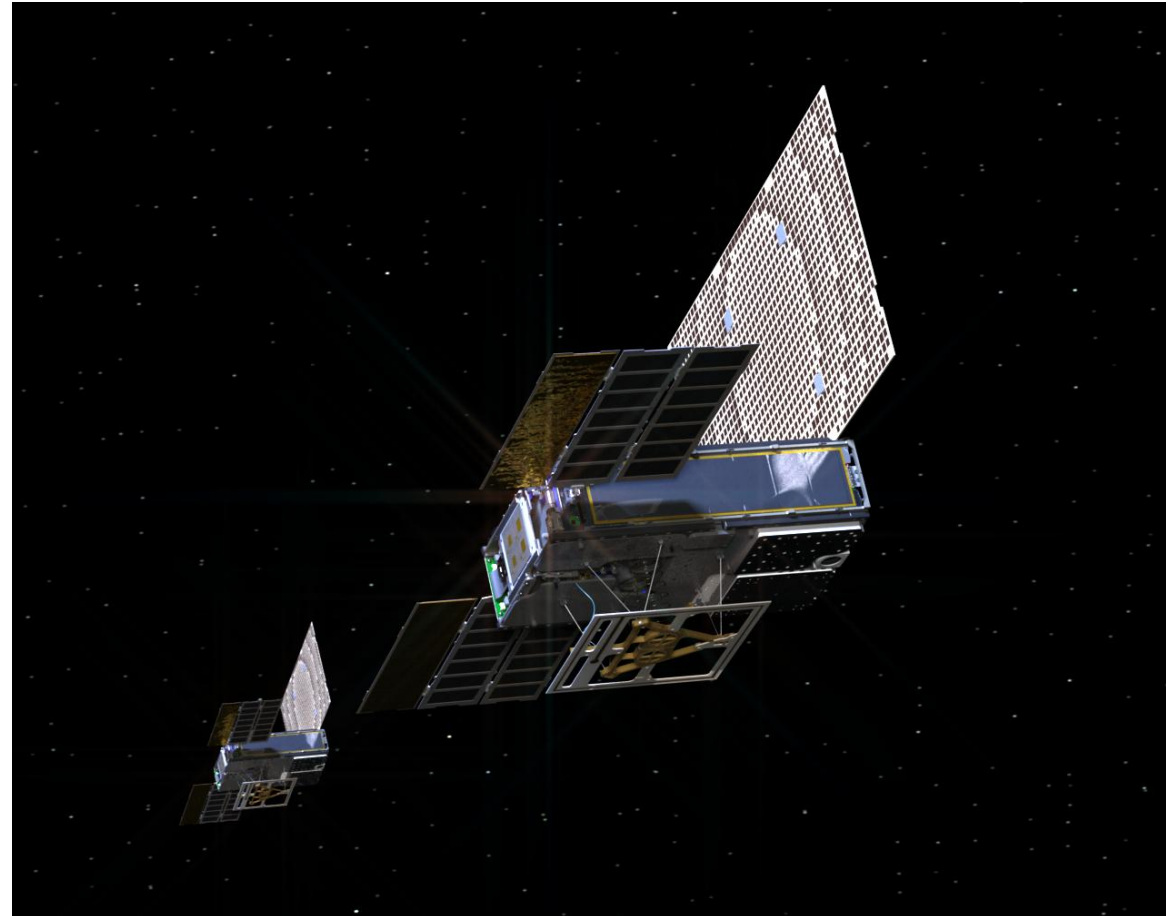


MarCO-B Images



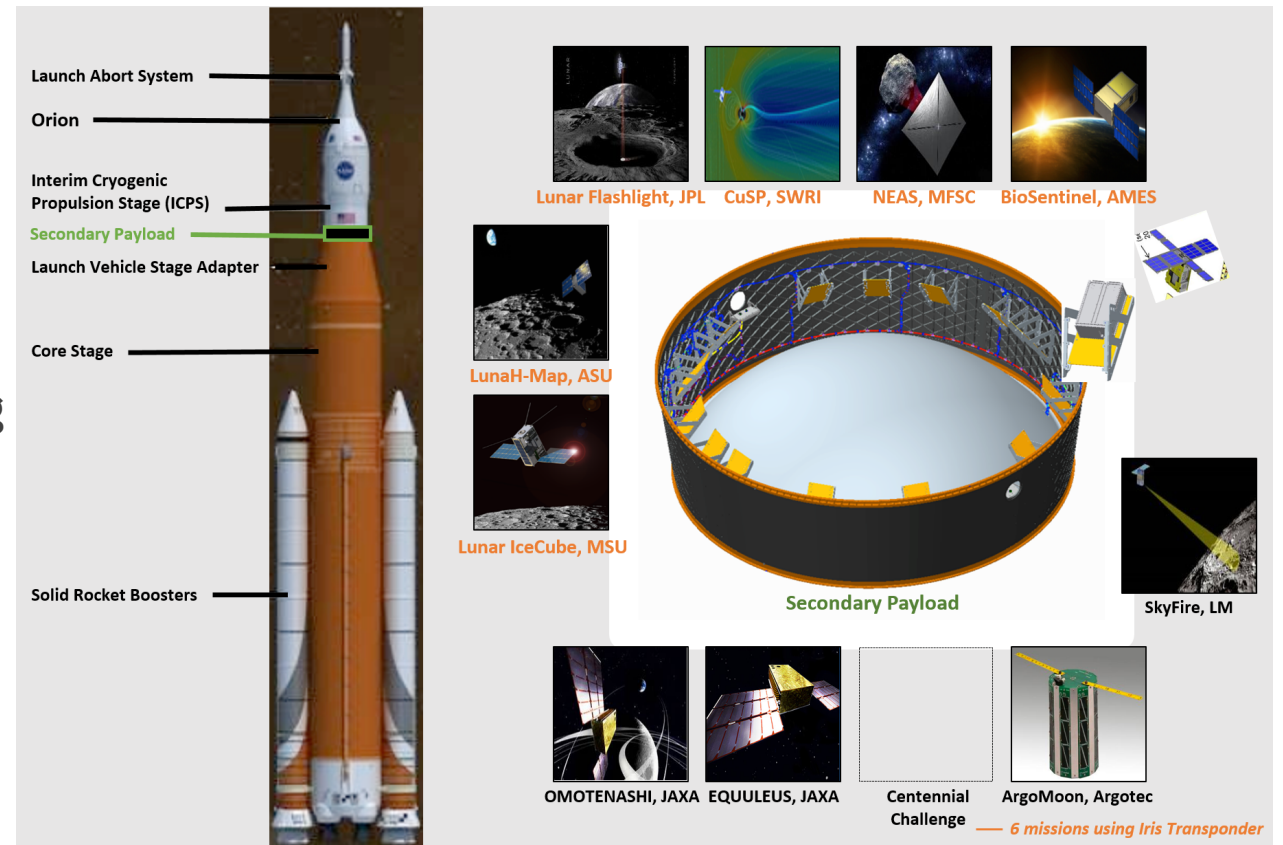
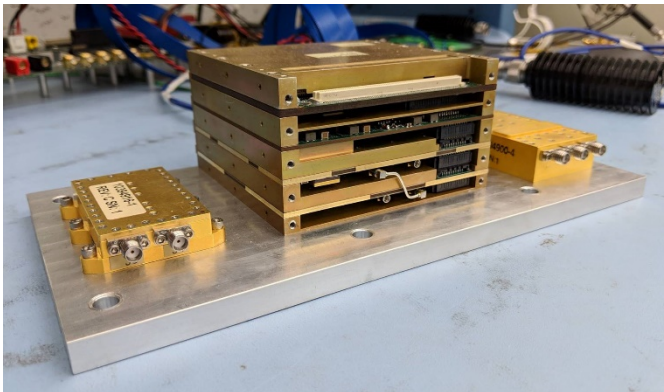
Current State of MarCO

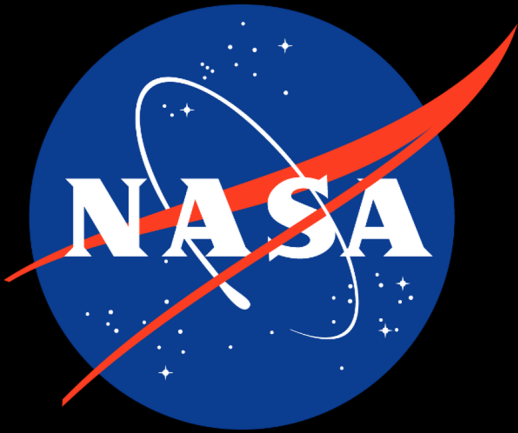
- Lost contact a few weeks after EDL
 - MarCO-B: Dec. 29, 2018
 - MarCO-A: Jan. 4, 2019
 - Current theory:
 - Issues on brightness sensors leading to attitude control trouble (greater distance requires more precise pointing) and inability to recharge batteries
- Heliocentric orbit; team may attempt to re-engage in early summer 2019



Future of Iris

- Iris V2.1 has been delivered to 6 cubesats on EM-1/Artemis-1
- No UHF Rx board
- Additional configurations available:
 - Expanded data rates (including those tested on MarCO!)
 - Turbo 1/2, 1/3 alongside 1/6
 - Option to enable/disable AOS framing





Jet Propulsion Laboratory

California Institute of Technology